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EFFECTS OF IN-ROW AND INTERROW SUBSOILING AND TIME OF NITROGEN APPLICATION ON GROWTH, STOMATAL CONDUCTANCE AND YIELD OF STRIP-TILLED CORN

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ABSTRACT

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The use of in-row subsoilers in conservation tillage systems in soils underlaid by tillage pans increases rooting depth, root proliferation and water infiltration. Interrow subsoiling 5 weeks after planting, to coincide with sidedress nitrogen applications, might be a practical method for further increasing infiltration of water from irrigation and high-intensity showers. Corn (*Zea mays* L.) was strip-till planted and grown under irrigation for 2 years at one location and 1 year at another to study the effects of subsoiling, placement and timing of nitrogen application (157 kg ha^{-1}) on plant growth, stomatal conductance and yield. Treatments included (1) not subsoiled, N applied at planting; (2) subsoiled in-row at planting, N applied at planting; (3) not subsoiled, N applied 5 weeks after planting; (4) subsoiled in-row at planting, N applied 5 weeks after planting; (5) subsoiled interrow, and N applied 5 weeks after planting; and (6) subsoiled in-row at planting and interrow 5 weeks after planting, N applied 5 weeks after planting. Nitrogen applied 5 weeks after planting resulted in higher yields than when applied at planting. In-row subsoiling at planting, interrow subsoiling 5 weeks after planting and subsoiling in-row at planting plus interrow 5 weeks later resulted in increased stomatal conductance between irrigations. Delaying N application resulted in decreased stomatal conductance in treatments that were in-row subsoiled at planting. Grain yields were lower without than with subsoiling, especially when N was applied at planting. When water was not limiting, subsoiling interrow 5 weeks after planting was as effective in increasing grain yield as in-row subsoiling at planting. In one test, the highest grain yield (9.96 t ha^{-1}) resulted from the cumulative effect of subsoiling in-row at planting plus interrow 5 weeks later.

INTRODUCTION

Root-restricting tillage pans are readily formed in many of the sandy soils of the Southern Coastal Plain of the United States (Kashirad et al., 1976; Reicosky et al., 1977). The use of in-row subsoilers in conservation tillage systems disrupts tillage pans and enables crop roots to access subsoil water and nutrients (Weatherly and Dane, 1979; Langdale et al., 1981; Chancy and Kamprath, 1982; Trouse, 1983). In addition, in-row subsoiling can result in increased infiltration and reduced surface runoff (Langdale et al., 1978).

The increased water infiltration and reduced surface runoff is an important aspect of strip tillage. As corn plants develop, however, a large portion of the rainfall or irrigation water that strikes the canopy is shed away from the row towards the row middle. Interrow subsoiling might provide a means for reducing runoff and increasing infiltration of water shed toward the row middle.

Delaying N applications 4—6 weeks after planting, to coincide with the crop's potential for utilization, can increase N effectiveness (Jung et al., 1972; Russelle et al., 1983). Coinciding N application may be a practical production practice.

Efficiency of N fertilizer in conservation tillage systems is often less than with conventional tillage. This difference may be due to increased leaching of NO_3-N (McMahon and Thomas, 1976; Thomas et al., 1981) and greater denitrification (Rice and Smith, 1982; Aulakh et al., 1984) resulting from increased soil moisture and organic carbon sources with conservation tillage. Nitrogen applied at planting to irrigated no-till crops before plant roots are extensive enough to effectively utilize it, is thus especially subject to losses via these mechanisms. At the same time, however, requirement for N fertilizer during early vegetative growth may be greater for crops grown in conservation tillage systems than in conventionally tilled systems since N mineralization is reduced and immobilization increased with conservation tillage (Baeumer and Bakermans, 1970; Kitur et al., 1984; Rice and Smith, 1984).

The objectives of this research were (1) to evaluate the benefit of in-row and interrow subsoiling on plant growth, water status, and yield, and (2) to determine the effect of timing of N application on plant growth, stomatal conductance and yield of corn grown in a conservation tillage system.

MATERIALS AND METHODS

The study was conducted for 2 years (1983, 1984) on a Norfolk sandy loam (fine-loamy, siliceous, thermic, Typic Paleudults) located at Shorter, Alabama, U.S.A. (85°54′W, 32°24′N), and for 1 year (1984) on a Dothan fine-sandy loam (fine-loamy, siliceous, thermic, Plinthic Paleudults) at Headland, Alabama, U.S.A. (85°19′W, 31°21′N). Different tiers were used in 1983 and 1984 with the Norfolk soil. Soils at both locations had a 4—8-cm thick tillage or traffic pan located 25—35 cm below the surface. Initial soil pH of the Norfolk soil was 5.9, and double acid extractable P, K, Ca and Mg (Hue and Evans, 1979) averaged 160, 150, 1300 and 140 kg ha^{-1}, respectively, for the Norfolk soil in 1983; 140, 140, 960 and 100 kg ha^{-1} in

TABLE I

Cover crops, planting dates, seeding rates (ha^{-1}), uniform plant populations (ha^{-1}), row widths (cm) and corn varieties used in 1983 and 1984

Year	Soil	Winter cover	Planting date	Seeding rate (ha^{-1})	Uniform plant population (ha^{-1})	Row width (cm)	Brand-variety
1983	Norfolk	Soya bean (*Glycine max* (L.) Merr.) stubble and winter weeds	5 April	128 000	49 000	68	Ring Around 1502
1984	Norfolk	Rye (*Secale cereale* L.)	7 April	99 000	59 000	68	Ring Around 1502
1984	Dothan	Rye (*Secale cereale* L.)	26 March	99 000	59 000	(Twin 18-cm rows on 90-cm centers)	Dekalb-T1230

1984. In the winter of 1984, 2.8 t ha^{-1} dolomitic limestone was applied to the Norfolk soil. The pH of the Dothan soil was 6.4, and P, K, Ca and Mg averaged 90, 110, 760 and 160 kg ha^{-1}, respectively. Soil test ratings for P and K for all tests were "high" (Cope et al., 1980); consequently the only P and K applied was as a starter fertilizer.

On the Norfolk soil, corn (*Zea mays* L.) was planted and appropriate treatments subsoiled with a Cole[1] no-till planter. Attached to the forward tool bar of this 3-row implement are smooth coulters for cutting through residue, followed by parabolic subsoilers. A pair of angled fluted coulters and hard-rubber press wheels behind each subsoil shank firm the soil over each subsoiled channel. Planter units, each consisting of a double-disk opener, seed hopper, and hard-rubber press wheel, are attached to the rear tool bar. On the Dothan soil, the Cole[1] implement was used for subsoiling, followed by seeding of twin 18-cm rows on either side of the subsoil channel with a John Deere[1] Flex-71 planter. Six-row plots, 9.1 m long, were planted in all tests. Planting dates and other cultural practices are listed in Table I.

The six treatments in this test included (1) not subsoiled, N applied at planting; (2) subsoiled in-row at planting, N applied at planting; (3) not subsoiled, N applied 5 weeks after planting; (4) subsoiled in-row at planting, N applied 5 weeks after planting; (5) subsoiled interrow, N applied 5 weeks after planting; and (6) subsoiled in-row at planting and interrow 5 weeks after planting, N applied 5 weeks after planting. Depth of subsoiling was 35—40 cm. The N rate was 157 kg ha^{-1} and N source was urea. For all treatments, the urea was banded on the soil surface approximately 10 cm from the row. The six treatments were within a split-plot design of 24 treatments which also included nitrogen source, nitrification inhibitors and nitrogen placement techniques as variables. Due to the extensive stomatal conductance determinations required within a limited time span, these six treatments were selected for monitoring with a steady-state porometer to determine the effects of subsoiling treatments and N application time on plant water status and yield.

Starter fertilizers of 22 kg ha^{-1} N, 9.6 kg ha^{-1} P, 18 kg ha^{-1} K and 25 kg ha^{-1} S in 1983 and 22 kg ha^{-1} N, 9.6 kg ha^{-1} P, 18 kg ha^{-1} K, 15 kg ha^{-1} S, 0.17 kg ha^{-1} B and 0.67 kg ha^{-1} Zn in 1984 were applied at planting. The starter fertilizers were applied in the subsoil track (35—40 cm depth) for treatments subsoiled at planting, and in a band 7 cm to the side of the row and incorporated 7 cm deep in treatments not subsoiled at planting. Plants were thinned 3 weeks after planting to a uniform population (Table I). In all tests, the winter cover crop (Table I) was killed with an application of 0.56 kg ha^{-1} paraquat (1,1′-dimethyl-4,4′-bipyridinium ion). Weeds

[1]Mention of trademark or proprietary product does not constitute a guarantee or warranty of the product by the U.S. Department of Agriculture or the Alabama Agricultural Experiment Station, and does not imply its approval to the exclusion of other products or vendors that may be suitable.

were effectively controlled with a tank mix of 1.68 kg ha^{-1} atrazine [6-chloro-*N*-ethyl-*N*′-(1-methylethyl)-1,3,5-triazine-2,4-diamine] and 1.68 kg ha^{-1} metolachlor [(2-chloro-*N*-2(2-ethyl-6-methylphenyl)-*N*(2-methoxy-1-methylethyl)acetamide], applied 21—27 days after planting.

Plant heights were recorded 52 days after planting in 1983 and 45 days after planting in 1984. During early silking, ear leaf samples were taken for N determinations. At physiological maturity, the two middle rows of each plot were harvested for grain yield determinations. Nitrogen concentrations were determined by Kjeldahl procedures in 1983, and with a LECO[1] CHN-600 carbon-hydrogen-nitrogen analyzer in 1984.

All tests were irrigated, and irrigation was scheduled with tensiometers when soil water potential at 15 cm depth was <-35 kPa. In 1984, at silking, sufficient water was applied to the tests to bring soil water potential to above -10 kPa and stomatal conductance and photosynthetically active radiation (PAR) were monitored at midday (12 00—14 00 h) with a Li-Cor[1] LI-1600 steady state porometer until soil water potential at 15 cm depth decreased to -50 kPa. This dry-down period of 11 days for the Norfolk soil and 7 days for the Dothan soil extended 1 day beyond the time when irrigation would have been applied in accordance with the scheduling tensiometers. At this time, soil water potential at 15 cm depth was -54 and -49 kPa for the Norfolk and Dothan soils, respectively. Porometer measurements were taken from the abaxial side of mature, unshaded leaves from the upper canopy. Single leaves from ten individual plants from the middle two rows of each plot were measured. Stomatal aperture and conductivity is strongly dependent on light intensity, therefore, during monitoring periods subjected to intermittent cloud cover, analysis of covariance (Freund and Littell, 1981) was used to adjust stomatal conductance measurements for PAR.

Statistical analyses included analysis of variance and multiple regression. Fisher's protected least significant difference ($P \leqslant 0.10$) and single degree of freedom tests were used for mean separation of preplanned comparisons.

RESULTS AND DISCUSSION

Early season plant growth and N concentration

In 1983, on the Norfolk soil, early season growth was retarded by low temperatures. The mean temperature for the 14-day period following emergence was 5.6°C below the 30-year norm of 11.3°C. Plant height 52 days after planting was greatest (40 and 36 cm) in treatments that had been in-row subsoiled at planting, with N application delayed until 5 weeks after planting (Treatments 4 and 6) (Table II.) Apparently, the poor growing conditions after planting reduced the effectiveness of N applied at planting; however, delaying N application in treatments that had not been in-row subsoiled (Treatments 3 and 5) resulted in the poorest plant heights (16 and 19 cm). In 1984, plant height was not affected by treatments on the Norfolk soil.

TABLE II

Effect of subsoiling and nitrogen timing on early season plant height (cm)

Treatment	Subsoiling		Time of N[c]	Plant height		
	In-row[a]	Interrow[b]		Norfolk 1983	Norfolk 1984	Dothan 1984
1	No	No	P	26	40	46
2	Yes	No	P	29	43	42
3	No	No	+5	19	44	42
4	Yes	No	+5	40	43	33
5	No	Yes	+5	16	47	45
6	Yes	Yes	+5	36	39	38
	$FLSD_{0.10}$			12.8	NS	7.4

[a] In-row subsoiled at planting.
[b] Interrrow subsoiled 5 weeks after planting.
[c] Time of N: P = planting; +5 = 5 weeks after planting.

Differences in plant height on the Dothan soil were caused by starter fertilizer placement and N applied at planting (Table II). Treatments not subsoiled in-row at planting (Treatments 1, 3 and 5) responded to the availability of starter fertilizer incorporated in a shallow band 7 cm from the row. Plant height was lowest (35.5 cm average) for in-row subsoiled treatments where N application was delayed until 5 weeks after planting (Treatments 4 and 6). Evidently, the corn roots reached and assimilated the starter fertilizer applied in the 7 × 7 cm shallow band much more rapidly than the starter placed deep in the subsoil channel. Occasional

TABLE III

Grain yield (t ha^{-1}) and leaf-N concentration (g kg^{-1}) at anthesis of strip-tilled corn grown on a Norfolk sandy loam in 1983, as affected by subsoiling and N application timing

Treatment	Subsoiling		Time of N[c]	Grain yield	Leaf N concentration
	In-row[a]	Interrow[b]			
1	No	No	P	5.38	17.4
2	Yes	No	P	6.51	18.1
3	No	No	+5	6.13	20.8
4	Yes	No	+5	8.34	20.5
5	No	Yes	+5	6.82	19.3
6	Yes	Yes	+5	8.86	18.0
	$FLSD_{0.10}$			1.64	NS

[a] In-row subsoiled at planting.
[b] Interrow subsoiled 5 weeks after planting.
[c] Time of N: P = planting; +5 = 5 weeks after planting.

TABLE IV

Grain yield (t ha^{-1}), leaf N concentration (g kg^{-1}) at anthesis and stomatal conductance (cm s^{-1}) of strip-tilled corn grown on a Norfolk sandy loam in 1984, as affected by subsoiling and N application timing

Treat-ment	Subsoiling		Time of N[c]	Grain yield	Leaf N concentration	Stomatal conductance[d]
	In-row[a]	Interrow[b]				
1	No	No	P	7.23	23.2	0.424
2	Yes	No	P	8.21	21.8	0.519
3	No	No	+5	8.20	23.8	0.433
4	Yes	No	+5	8.06	23.0	0.481
5	No	Yes	+5	8.35	24.4	0.558
6	Yes	Yes	+5	8.24	23.3	0.542
	$FLSD_{0.10}$			[e]	NS	0.063

[a]In-row subsoiled at planting.
[b]Interrow subsoiled 5 weeks after planting.
[c]Time of N: P = planting; +5 = 5 weeks after planting.
[d]Mean stomatal conductance of Days 185—195 measured between 12 00—14 00 h.
[e]Within non-subsoiled treatments, yield from N applied at planting is less ($P \leqslant 0.06$) than N applied 5 weeks after planting, using single degree of freedom test of Treatment 1 vs. Treatment 3. Within treatments receiving N at planting, yield of non-subsoiled treatment is less ($P \leqslant 0.06$) than in-row subsoiled treatment, using single degree of freedom test of Treatment 1 vs. Treatment 2.

TABLE V

Grain yield (t ha^{-1}), leaf N concentration (g kg^{-1}) at anthesis and stomatal conductance (cm s^{-1}) of strip-tilled corn grown on a Dothan fine-sandy loam in 1984, as affected by subsoiling and N application timing

Treat-ment	Subsoiling		Time of N[c]	Grain yield	Leaf N concentration	Stomatal conductance[d]
	In-row[a]	Interrow[b]				
1	No	No	P	8.12	30.3	0.388
2	Yes	No	P	8.62	31.5	0.439
3	No	No	+5	8.68	38.3	0.364
4	Yes	No	+5	8.73	35.9	0.400
5	No	Yes	+5	9.05	37.3	0.419
6	Yes	Yes	+5	9.96	35.4	0.450
	$FLSD_{0.10}$			[e]	[f]	0.021

[a]In-row subsoiled at planting.
[b]Interrow subsoiled 5 weeks after planting.
[c]Time of N: P = planting; +5 = 5 weeks after planting.
[d]Mean stomatal conductance of Days 171—178 measured between 12 00—14 00 h.
[e]Yields of Treatment 6 differ ($P \leqslant 0.01$) from non-subsoiled treatments using single degree of freedom test of Treatment 6 vs. Treatments 1 and 3. Yields of Treatment 6 differ ($P \leqslant 0.03$) from in-row subsoiled treatments using single degree of freedom test of Treatment 6 vs. Treatments 2 and 4.
[f]Leaf N in treatments receiving N at planting is less ($P \leqslant 0.01$) than in treatments receiving N 5 weeks after planting using single degree of freedom test of Treatments 1 and 2 vs. all other treatments.

problems with availability of deep placed starters have been reported (Touchton, 1985).

At anthesis, ear leaf N concentrations were not affected by treatments on the Norfolk soil (Tables III and IV), but on the Dothan soil, leaf N (Table V) was higher when N was applied 5 weeks after planting (36.7 g kg^{-1} average) than when applied at planting (30.9 g kg^{-1} average) as evidenced by single degree of freedom comparison.

Grain yield

In 1983, on the Norfolk soil, treatment effects on grain yield were amplified by low rainfall (3 cm in 47 days) following emergence (Fig. 1), and lack of irrigation (system failure) until Day 152. Although yield increases to subsoiling generally occur when drought stress periods are of short duration (Trouse, 1983; Box and Langdale, 1984) the extended drought period in 1983 occurred during the early growth stages when grain yield is less sensitive to drought stress (Denmead and Shaw, 1960; Bennett and Hammond, 1983). Highest yields (8.34–8.86 t ha^{-1}) were from treatments that had been in-row subsoiled at planting with N applied 5 weeks after planting (Treatments 4 and 6) (Table III). Applying N at planting without subsoiling resulted in the lowest yield (5.38 t ha^{-1}). Time of N application within non-subsoiled treatments (Treatments 1 and 3) had no effect on yields (5.76 t ha^{-1} average). However, N applied 5 weeks after planting improved yields in treatments that were in-row subsoiled at planting (8.34 vs. 6.51 t ha^{-1}). Apparently, early-season drought stress in the non-subsoiled treatments reduced efficient utilization of N. Within treatments where N was applied 5 weeks after planting, yields from in-row subsoiling at planting (Treatment

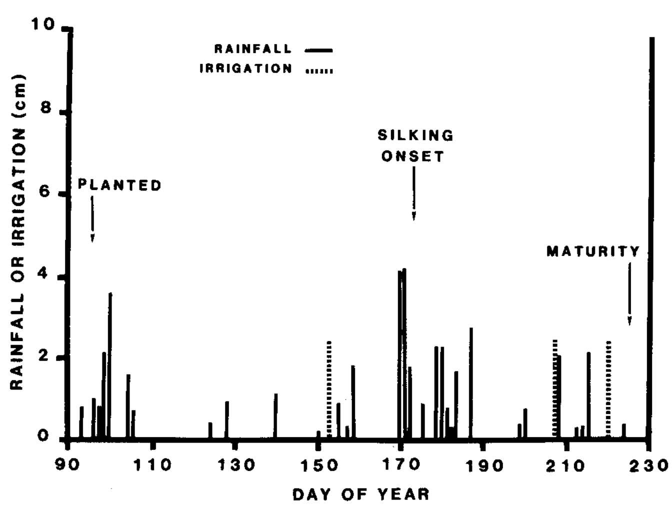

Fig. 1. Rainfall and irrigation on Norfolk sandy loam during 1983.

4) did not differ ($P \leqslant 0.10$) from subsoiling between the row 5 weeks after planting (Treatment 5).

In 1984, water was sufficiently supplied on the Norfolk site (Fig. 2). Based on single degree of freedom contrasts, the only yield differences among treatments occurred between N application time within non-subsoiled plots (Treatment 1 vs. Treatment 3), and N applied at planting treatments that either had or had not been in-row subsoiled at planting (Treatment 1 vs. Treatment 2) (Table IV). It is possible that the frequent irrigation and rainfall (Fig. 2) leached N applied at planting below the tillage pan before corn roots were extensive enough to effectively utilize the applied N. When N application was delayed for 5 weeks, root development was adequate to effectively utilize the N fertilizer with a consequent 13.5% yield increase. If the N applied at planting had leached below the tillage pan, this would also explain the greater yield of the in-row subsoiled treatment over the non-subsoiled treatment since water was not severely limited. Chancy and Kamprath (1982) attributed greater yields in subsoiled treatments to possible extraction of leached N below the tillage pan as well as to improved utilization of soil water. Yield differences between subsoiled treatments within N at planting might also have been due to improved root growth and consequent improved water status with subsoiling as indicated by differences in stomatal conductance (Table IV). This will be discussed in the next section.

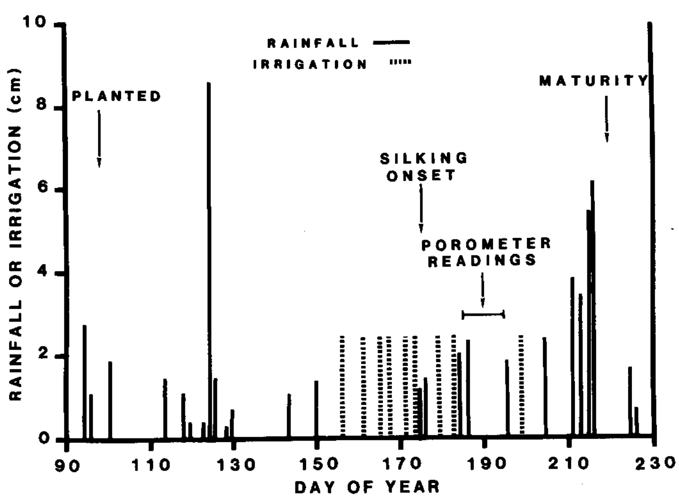

Fig. 2. Rainfall and irrigation on Norfolk sandy loam during 1984.

Rainfall and irrigation were sufficient at the Dothan soil site in 1984 (Fig. 3). As in both years on the Norfolk soil, the lowest yield (8.12 t ha^{-1}) resulted from applying N at planting and not subsoiling (Treatment 1) (Table V). Time of N application had no effect on yields of subsoiled (Treatment 2 vs. Treatment 4) or non-subsoiled (Treatment 1 vs. Treatment 3) treatments ($P \leqslant 0.10$) (Table V). Subsoiling in-row at planting plus interrow 5 weeks later (Treatment 6) increased yields 18.5% over non-subsoiled treatments (Treatments 1 and 3). Within treatments receiving N fertilizer 5 weeks after planting, yields were equivalent from subsoiling in-row plus interrow (Treatment 6), or interrow only (Treatment 5) ($P \leqslant 0.10$), however, subsoiling in-row plus interrow increased yields over the treatment that had been subsoiled in the row only (Treatment 4). Within treatments receiving N 5 weeks after planting, yields from in-row subsoiling (Treatment 4) or interrow subsoiling (Treatment 5) were equivalent.

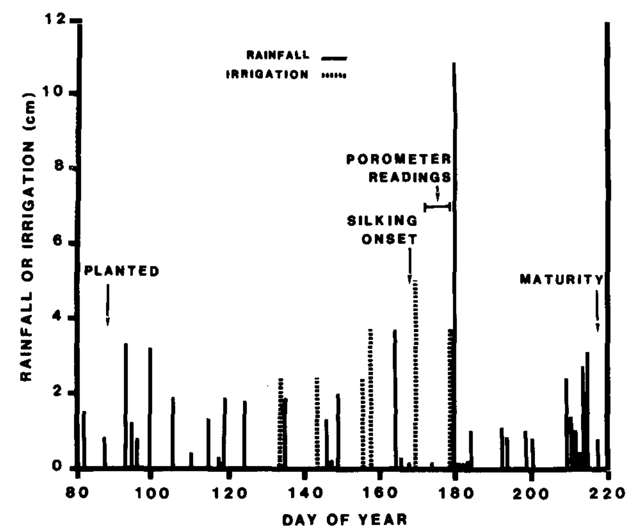

Fig. 3. Rainfall and irrigation on a Dothan fine-sandy loam in 1984.

Stomatal conductance

Plant water status during the 7- or 11-day dry-down period following irrigation, as measured by midday stomatal conductance, was significantly affected by treatment on both soil sites. On the Dothan soil, the in-row plus interrow subsoiled treatment (Treatment 6), and the in-row subsoiled N at planting treatment (Treatment 2) maintained higher stomatal conductivity during the dry-down period than other treatments (Fig. 4, Table V). The data also indicate that at this location, delaying N application to plants that were in-row subsoiled lowered stomatal conductivity. This effect may be explained by the increased early-season plant growth in the in-row subsoiled N at planting treatment (Treatment 2) as compared to the in-row subsoiled N at 5 weeks treatment (Treatment 4) (Table II). This suggests that plants in the in-row subsoiled treatment where N was applied at planting had increased root growth below the tillage pan, which would

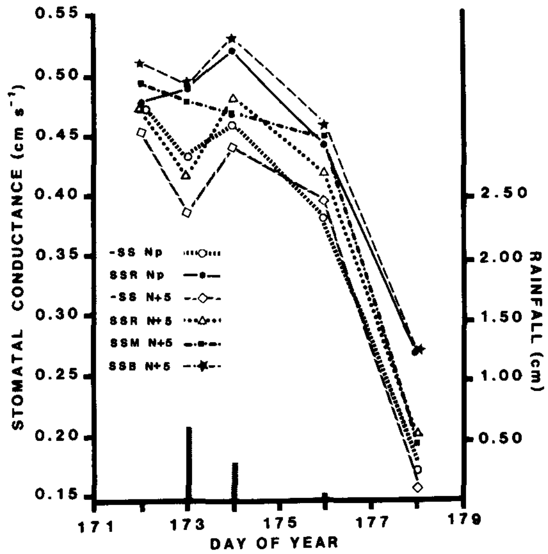

Fig. 4. Stomatal conductance of no-till corn grown on a Dothan fine-sandy loam over a 7-day period following irrigation to bring soil water potential to above -10 kPa. Np, N at planting; N +5, N at 5 weeks; -SS, not subsoiled; SSR, in-row subsoiled at planting; SSM, subsoiled interrow (middle) 5 weeks after planting; SSB, subsoiled both in-row at planting and interrow 5 weeks later.

allow more efficient water uptake later in the season. A large proportion of corn root formation occurs within 5 weeks after planting. Taylor et al. (1970) reported that corn roots in a rhizotron reached the 200-cm depth in 39 days, and that approximately 65% of the roots that intersected a 100-cm transect at a 60-cm depth reached this depth within 45 days after planting. Nitrogen applied at planting would thus favor greater root formation at depths below the tillage pan. The non-subsoiled treatments had the lowest stomatal conductance.

Data in Table V indicate that plant tissue N concentration at anthesis and degree of water stress, as measured by stomatal conductance, both affected yield, and that improved N status or stomatal conductance could substitute for each other in improving yield. Reddy et al. (1981) reported that nitrogen and available soil moisture could substitute for each other in reducing evapotranspiration ratio (ETR = kg water used in season kg^{-1} ha^{-1} grain yield of corn) when one of them becomes limiting. Eck (1984) reported that adequate N slightly increased corn yield even under drought stress, and greatly increased yield when plants were not stressed. The multiple regression model, Yield (t ha^{-1}) = -13.52 + 151.39 stomatal conductance (cm s^{-1}) + 1658.6 Leaf N (g kg^{-1}) -229.(Leaf N)^2 ($R2$ = 0.71), describes the functional relationship between yield, leaf N and stomatal conductance for the Dothan soil in 1984. Interaction terms which did not significantly contribute to the model were not included.

At the Norfolk soil site, the highest stomatal conductivity was maintained in the in-row plus interrow (Treatment 6), and interrow only subsoiled (Treatment 5) treatments, where N was applied 5 weeks after planting, and in the in-row subsoiled N at planting treatment (Treatment 2) (Fig. 5, Table IV). The increased stomatal conductivity of the interrow subsoiled only treatment on the Norfolk soil, compared to the Dothan soil, may be due to either the narrower row spacing at this location or the use of different corn hybrids at each location. As on the Dothan soil, the non-subsoiled treatments (Treatments 1 and 3) had the lowest stomatal conductivity. No functional relationship between yield and stomatal conductance and/or leaf N was evident at the Norfolk soil site.

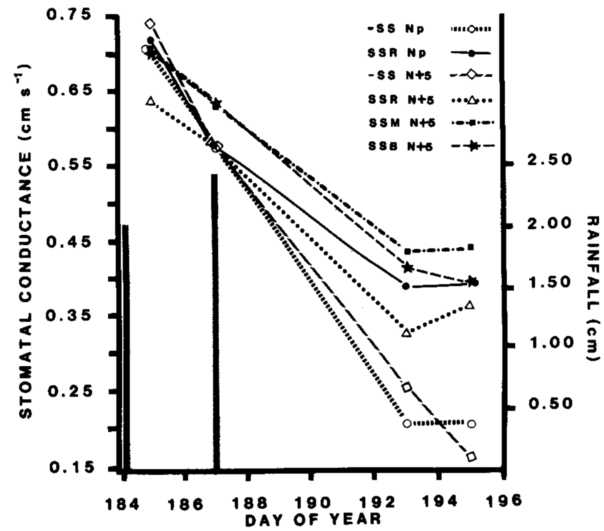

Fig. 5. Stomatal conductance of no-till corn grown on a Norfolk sandy loam over an 11-day period following irrigation (and rainfall) to bring soil water potential to above -10 kPa. Np, N at planting; N +5, N at 5 weeks; -SS, not subsoiled; SSR, in-row subsoiled at planting; SSM, subsoiled interrow (middle) 5 weeks after planting; SSB, subsoiled both in-row at planting and interrow 5 weeks later.

CONCLUSIONS

In these tests, subsoiling improved plant water status and yield even in years when water was supplied according to recommended practices. Delaying nitrogen application until 5 weeks after planting proved more efficient than applying the N at planting. When nitrogen was applied 5 weeks after planting, and when water was not severely limited, interrow subsoiling 5 weeks after planting was as effective in increasing yields as in-row subsoiling at planting. In one test, the cumulative effect of subsoiling in-row at planting plus interrow 5 weeks later improved yields. This treatment effect may be due not only to increased root growth and water uptake below the tillage pan (Campbell et al., 1974; Weatherly and Dane, 1979), but also to increased infiltration of rainfall and irrigation water (Campbell et al., 1974; Langdale et al., 1978). Although delaying N applications on these light-textured soils improved yields, adequate N is also needed early in the plant's growth to fully take advantage of the benefits of subsoiling. Research is needed to define the most efficient rate of N supplied at planting to that applied later in the season to obtain maximum benefit of subsoiling practices in increasing yields.

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